Knight: Chapter 16

A Macroscopic Description of Matter

(*Phase Changes & Ideal Gases*)

Quiz Question 1

Which is the largest increase of temperature?

$\Delta T_K = \Delta T_C$

1. An increase of 1°F.
2. An increase of 1°C.
3. An increase of 1 K.
4. Both 2 and 3, which are the same and larger than 1.
5. 1, 2, and 3 are all the same increase.

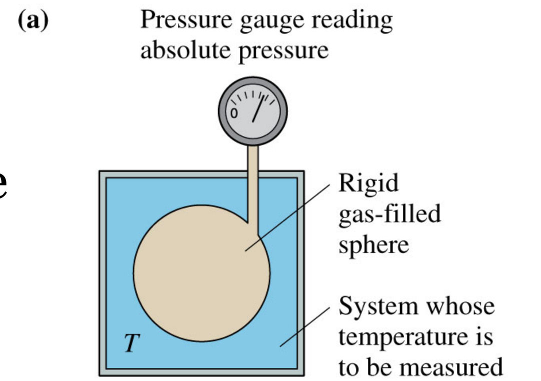
Absolute Zero & Absolute Temperature

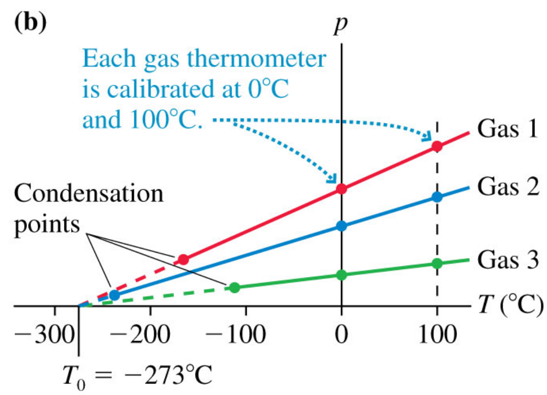
- (a) shows a constant-volume gas thermometer.
- (b) shows a pressure vs. temperature plot for 3 different gases.

Notice:

  - There is a *linear relationship* between *temperature and pressure*.
  - All gases extrapolate to *zero* pressure at the *same* temperature: $T_0 = -273°C$.

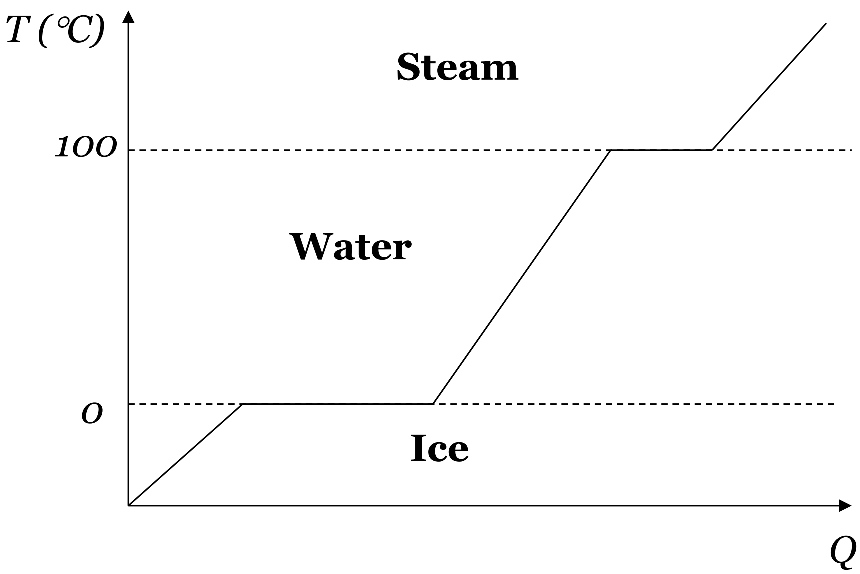
- This is called *absolute zero*, and forms the basis for the *absolute temperature scale* (Kelvin).





Phase Changes

Discussion: ice $\rightarrow$ steam:



What about during a phase change when $\Delta T = 0$?

Where does the heat go?

Phase Changes

Melting or freezing point…

- Temperature at which a substance changes phase from *solid* to *liquid* or from *liquid* to *solid*.

Boiling or condensation point…

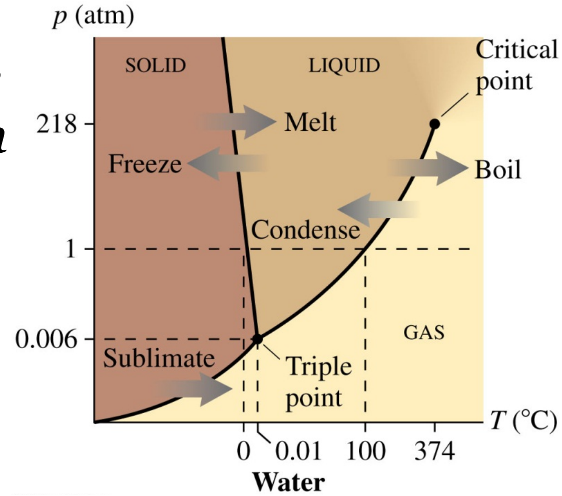
- Temperature at which a substance changes phase from *liquid* to *gas* or from *gas* to *liquid*.

Phase equilibrium…

- At the *melting* point, *liquid & solid* can coexist in any amount.
- At the *boiling* point, *gas & liquid* can coexist in any amount.

Phase Diagram…

- used to show how the *phases* & *phase changes* of a substance vary with *both temperature* & *pressure*.



Notice:

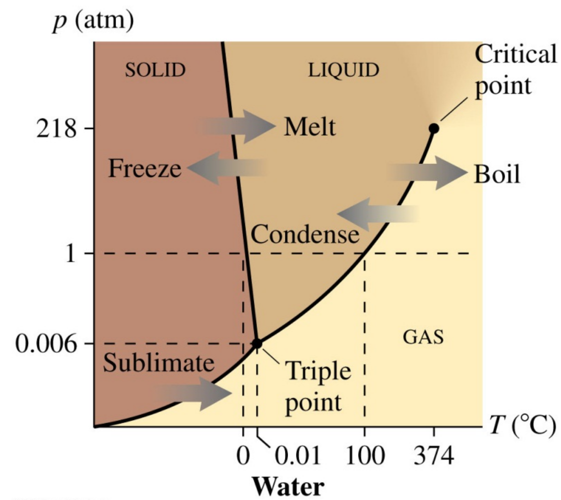
- @ 1 atm of pressure, H_2O crosses the solid-liquid boundary at 0°C and the liquid-gas boundary at 100°C.

- When $p < 1$ atm, H_2O *freezes* at a temperature *above* 0°C & *boils* at a temperature *below* 100°C.
- When $p > 1$ atm, the temperature of boiling water is *higher*.

Quiz Question 2

If the pressure of liquid H_2O is suddenly *decreased*, it is possible that the H_2O will

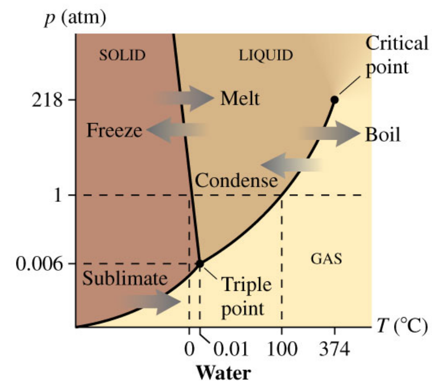
1. freeze.
2. condense.
3. boil.
4. Either 1 or 2
5. Either 1 or 3

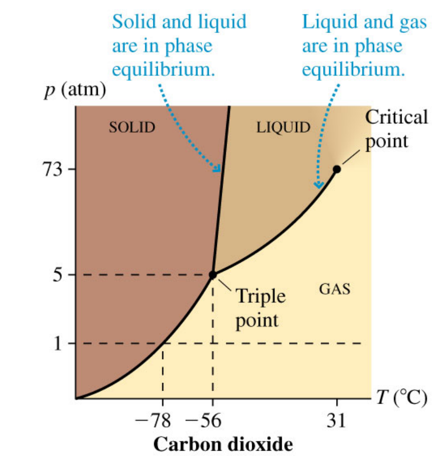


Phase Diagram for H_2O & CO_2

Compare the *slope* of the solid-liquid boundary (phase equilibrium line)..

- Start *compressing* CO_2 at room temp..
  - gas -> liquid -> solid
- Start *compressing* H_2O at room temp..
  - gas -> liquid
- Start *compressing* solid H_2O at $T = 0°$ C..
  - solid -> liquid!
  - Why?





Phase Diagram for H_2O & CO_2

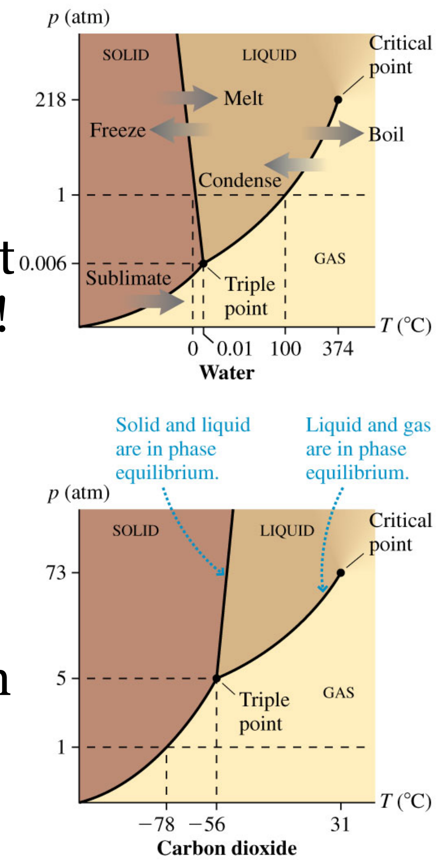
Note the special points:

Critical point..

- Liquid-gas boundary ends.
- NO clear distinction between liquid & gas at pressures or temperatures above this point!
  - Fluid varies continuously between high & low density without a phase change.

Triple point..

- Phase boundaries meets
- 1 value of temperature & pressure for which all 3 phases can coexist in phase equilibrium



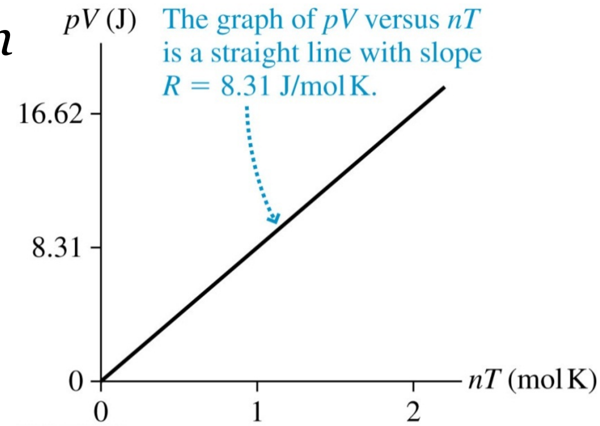
Ideal-gas model..

- atoms in a gas are modeled as *hard spheres*.
  - occasionally bounce off each other in *perfectly elastic collisions*.
- Excellent model for gases if:
  1. the density is *low*.
  2. the temperature is *high*.

Ideal gas is
Low Density
&
High Temp

Ideal-gas law..

For an ideal gas in *thermal equilibrium*



$$\boxed{pV = nRT}$$

where $\boxed{R = 8.31 \text{ J/mol K}}$ is the *universal gas constant*.

Notice:

- one gets the *same slope* for a pV vs nT graph for *any* gas!
- $[p] = Pa \; , \; [V] = m^3 \; , \; [T] = K$

i.e. 16.3: Calculating a gas pressure

100 g of oxygen gas is distilled into an evacuated 600 cm^3 container.

What is the gas pressure at a temperature of 150° C?

$M = 0.100\ kg$

$V = 600\ cm^3$

$T = 150°C$

$P = ?$

$PV = nRT$

$P = \frac{nRT}{V}$

$P = \frac{3.1\ mol\,(8.31\ J/mol)(423\ K)}{(6.00 \times 10^{-4}\ m^3)}$

$P = 1.8 \times 10^7\ Pa$

$n = \frac{M}{m} = \frac{0.100\ kg}{0.032\ kg/mol} = 3.1\ mol$ $\quad V = 600\ cm^3 \times \frac{m^3}{1.0 \times 10^6\ cm^3}$

$n = 3.1\ mol$

$T = 423\ K$

$V = 6.00 \times 10^{-4}\ m^3$

$P = 1.8 \times 10^7\ Pa$

Ideal-gas law in a sealed container…

$$\frac{PV}{T} = nR$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Ideal-gas law in a sealed container...

$$\boxed{\frac{p_f V_f}{T_f} = \frac{p_i V_i}{T_i}}$$

i.e. 16.4: Calculating a gas temperature

A cylinder of gas is at 0° C. A piston compresses the gas to *half* its original volume and *three times* its original pressure.

What is the final gas temperature?

$T = 273\ K$

$$\frac{P_0 V_0}{T_0} = \frac{P_1 V_1}{T_1} \qquad V_1 = \frac{1}{2} V_0 \qquad P_1 = 3 P_0$$

$$\frac{P_0 V_0}{T_0} = \frac{3P_0(\frac{1}{2}V_0)}{T_1}$$

$$\frac{T_0}{P_0 V_0} = \frac{T_1}{3P_0(\frac{1}{2}V_0)}$$

$$T_1 = \frac{T_0}{P_0 V_0}(3P_0)(\tfrac{1}{2}V_0)$$

$$T_1 = \frac{3 T_0 \cancel{P_0} \cancel{V_0}}{2 \cancel{P_0} \cancel{V_0}}$$

$$T_1 = \frac{3T_0}{2}$$

$T_1 = 410\ K$

Ideal-gas law - *alternative form..*

$$PV = \frac{N}{N_A} RT = N\underbrace{\left(\frac{R}{N_A}\right)}_{K_b} T$$

$K_b = J/K$

$$PV = N(K_b)T$$

$K_b = 1.38 \times 10^{-23}\ J/K$

Ideal-gas law - *alternative form..*

Boltzmann's constant
= 1.38 x 10^{-23} J/K

$$\boxed{pV = Nk_BT}$$

— Molecules given

Number of molecules

in Kelvin!

Quiz Question 3

Two identical cylinders, A and B, contain the *same* type of gas at the *same* pressure. Cylinder A has *twice* as much gas as cylinder B.

$PV = nRT$ $\quad n_A = 2n_B$

Which is true?

$T = \frac{PV}{nR}$

1. $T_A < T_B$
2. $T_A = T_B$
3. $T_A > T_B$
4. Not enough information to make a comparison.